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The Local Fit Constants From Near Surface Seismic Measurements for Shear Wave Velocity Estimation in the Eastern Niger Delta

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ABSTRACT
Near surface seismic data from refraction survey in some parts of Eket were used to determine the local fit constants for shear wave velocity estimation from V_s-V_p relation. Using the paint package of Windows 7.1, the travel time with corresponding distance were picked directly from the pulse of the seismogram. The plot of each location resulted in the compressional wave velocity obtained from the reciprocal of the slope of each layer of t-X graphs. Shear wave velocity was obtained using poison ratio of 0.2 as the first layer of the study area was more of sand formation. Regression analysis was carried out to obtain constants for Vs-Vp relation. Castagna constants for Vs-Vp are 0.8621 for a and -1.1724 for b (that is, a = 1.16 and b = 1.36 from Vp-Vs relation). The major findings resulting from the local fit for this area, indicate a and b as 0.611 and 0.2862 respectively. The result shows that Castagna constants are not suitable for estimation of shear wave velocity within the near surface region of this area; local fits constants for Castagna Equation should always be determined in the region where Castagna did not conduct a survey as this case has shown. We have generated compressional wave velocities and subjected them to the Castagna Equation with his constants as well as the local fits constants to determine shear wave velocity; the result were not similar and to confirm the outcome of the poison ratio, negative values were obtained with Castagna constants while positive values agree with local fits. The local fit constants satisfied the original Equation relating poison ratio with compressional wave velocity and shear wave velocity. The probability value is very much lower than 0.01 (about zero) which agree with the coefficient of determination and correlation coefficient of about one.

KEYWORDS*: Constants, Shear wave velocity, Near surface seismic data, V_s-V_p relation, Regression, Poisson's ratio, refraction.*

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I. INTRODUCTION

Reliable shear wave velocity information for assessment of mechanical properties of rock formation compensates the likely extra expenses for acquiring a shear tool. According to the studies carried out to estimate mechanical properties of subsurface layer, having shear velocity data is essential to make reliable calculations (Ameen et al., 2009; Rasouli et al., 2011; Zoback, 2007). Shear-wave velocity statistics are suitable for many seismic interpretation applications, including bright spot and amplitude-versus-offset analyses and multicomponent seismic interpretations. Measured shear wave velocity information is frequently unavailable (Greenberg and Castagna, 1992) and if available, may be dominated with noise.

One of the most extensively used correlations to predict shear wave velocity is Castagna Equation. Castagna et al. (1993) proposed empirical equations for calculation of shear wave velocity in sandstone, limestone, shale and dolomite rocks. Castagna correlation overestimates shear wave velocity; this happened consistently, resulting in a correlation coefficient of 0.96 between the real and predicted values. This means that this correlation results in a relatively high precise but low accurate estimation (Maleki et al., 2014).

For the purpose of this study, Castagna empirical relation was adopted and modelled to yield a linear relation with effect of local fit constants for estimation of shear wave velocity. With this result, V_p/V_s ratio can be achieved and used to identify other quantities of seismic data. This cannot be done without carrying out regression analysis, which is one of the widely applied statistical tools for the study of relationships between a dependent variable of interest and a set of independent (related predictor) variables. Regression equation offers an approximation to the actual functional relationship between the parameters of interest.

Location and Geology

The locations are in Eket Local Government Area. Eket, is located within latitudes 4°00'N to 4°30'N and longitudes 7°45'E to 8°00'E (Figure 1). The shot locations include latitude 4.6384^0N and longitude 7.9174^0E by Mobil peagasus club, Esuene Way, latitude 4.6500^0N and longitude 7.9333^0E at All Weather Road, Idua, latitude 4.6500^0N and longitude 7.9333^0E at Government Primary School, Main School Road, latitude 4.4746^0N and longitude 7.9238^0E at Government Primary School, Hospital Road, latitude 4.6732^0N and longitude 7.9814^0E by Salvation Army Primary School, Ikot Use, latitude 4.6574^0N and longitude 7.9779^0E by Heritage Polytechnic, and latitude 4.6765^0N and longitude 7.9228^0E by The Apostolic Church, Nduo Eduo.

Resources like palm produce is very common in the area; the people are also into production of sea food. Cassavas, plantain, banana among other crops are available in abundance. The area is also very rich in crude oil. The wet season and the dry season are the two distinct seasons experienced. Thick Sedimentary formations of late Tertiary and Holocene ages are seen and the surface is about 1.76 x 10^2m above sea level (Atat et al., 2013).

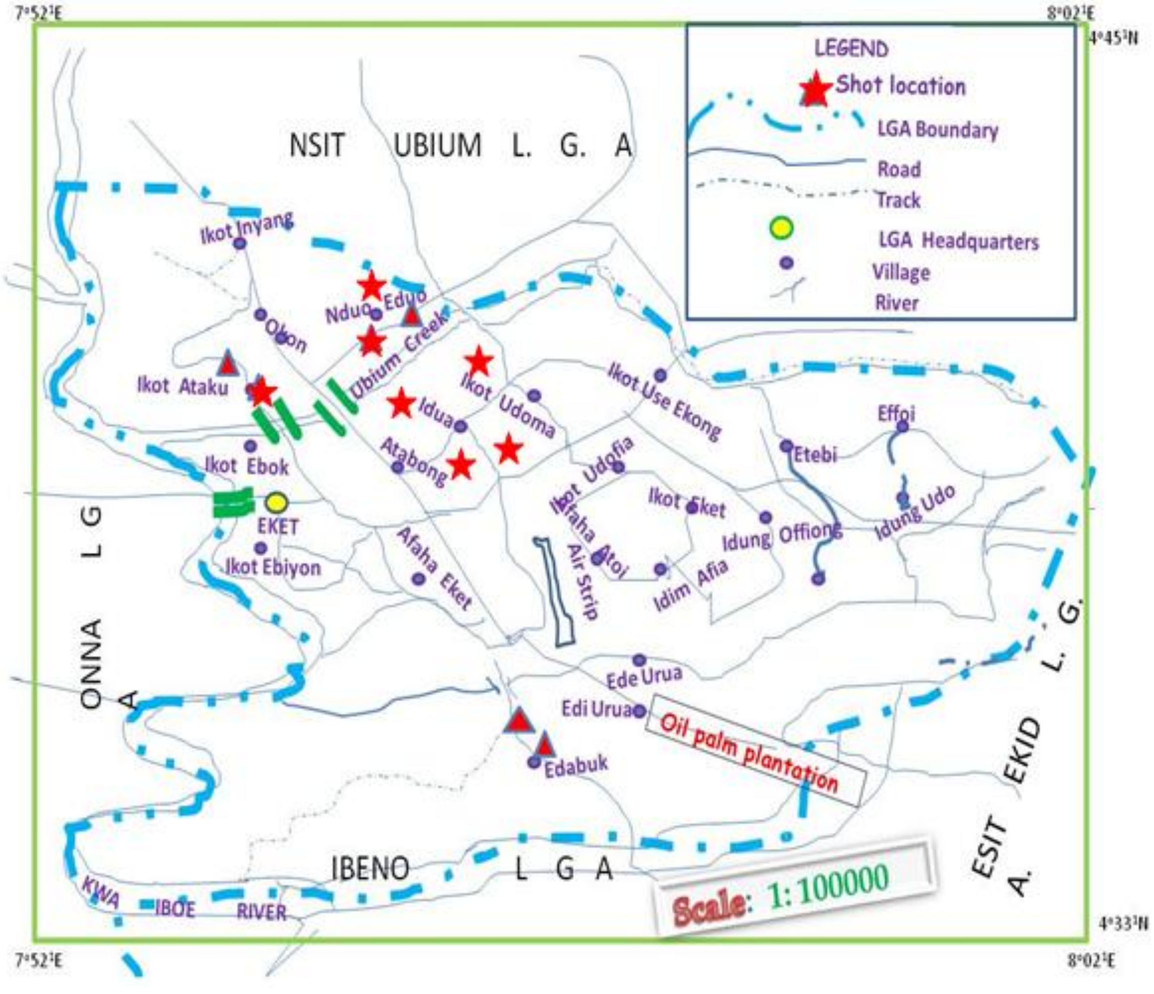


Figure 1: The Map of the study area (Atat et al., 2013).

Previous works on seismic refraction method

Researchers have worked on the velocities of near surface (Atat et al., 2012; Essien et al., 2014; Bachrach et al., 1998; Baker et al., 1999; Omodu and Ebeniro, 2005). At shallow depths, seismic velocities are highly affected by porosity (Pickett, 1963), the pore content and the degree of saturation. The seismic refraction method (twelve or multichannel analysis of surface waves), has been used for site investigation (Park et al., 1999). Geophysicists studied the shear and primary wave velocity profile using the seismic refraction method located at Jenalik Hulu, Kuala Kangsar, Malaysia. Uyanik, 2010 also measured these velocities in an unconsolidated top-soil and compared his results. Most of the in-situ tests were conducted adjacent to the proposed route (alignment 1 of the package II Kuala Kangsar – Grik Road Improvement Project). The result from their studies proved that the method is useful for engineering assessment of unsaturated granitic residual soil even for a highly complicated site. A good correlation between the stiffness was obtained from the seismic refraction method.

Poisson's Ratio

This is an elastic parameter or constant which is defined as the ratio of transverse contractional strain to longitudinal extensional strain. In other words, a measure of the degree to which a material expands outwards when squeezed, or equivalently contracts when stretched (Sheriff, 2002). It is a measure of the compressibility of the material perpendicular to applied stress. This elastic constant is named after Simeon Poisson, a French mathematician. Poison's ratio (σ) can be stated in terms of properties that can be measured in the field, which also include velocities of P-waves and S-waves (Equation 1).

$$\sigma = \frac{V_p^2 - 2V_s^2}{2(V_p^2 - V_s^2)} \qquad (1)$$

Where σ is Poisson's ratio, V_p is compressional wave velocity, V_s is shear wave velocity.

Note that if $V_s = 0$, then poison equals 0.5. This indicates that either a fluid, because shear waves do not pass through fluids or a material that maintains constant volume irrespective of stress, also called an ideal incompressible material. Poisson's ratio for carbonate rocks is about 0.3; about 0.2 for sandstones and greater than 0.3 for shale. The Poisson's ratio of coal is about 0.4 (Schlumberger Oilfield Glossary on 25-06-2021. https://glossary.oilfield.slb.com). Shear wave velocity can then be obtained from Equation 2.

$$V_s = V_p \left[\frac{1-2\sigma}{2(1-\sigma)}\right]^{1/2} \qquad (2)$$

Where σ is poison ratio, V_p is compressional wave velocity, V_s is shear wave velocity.

Previous works on Castagna Equation

Castagna et al. (1985) came up with a relationship between P-wave and S-wave velocities derived from linear plotting of bore-hole measurements as stated in Equation 3.

$$V_p = aV_s + b \qquad (3)$$

Where V_p is compressional wave velocity, V_s is shear wave velocity, a and b are constants. The values of a and b are different for different rocks that are presented by researches based on their observations. He suggested a relationship for small grained rocks such as mudstones (Equation 4).

$$V_p = 1.16V_s + 1.36 \qquad (4)$$

Where V_p is compressional wave velocity, V_s is shear wave velocity (Castagna et al., 1985).

Castagna and Thomas gave Equations 5 and 6 shear wave velocity estimation for sandstone and shale lithology.

$$V_s = 1.16V_p - 0.8559 \qquad (5)$$

$$V_s = 0.77V_p - 0.8674 \qquad (6)$$

Where V_p is compressional wave velocity, V_s is shear wave velocity.

Han (1986) investigation resulted in Equation 2.7 for shale.

$$V_s = 0.7936V_p - 0.7868 \qquad (7)$$

Where V_p is compressional wave velocity, V_s is shear wave velocity.

Maleki et al. (2014) also worked on the constants and obtained them as 0.458 and 0.3904 for a and b respectively. This means that the Vp-Vs relation gives Equation 2.8.

$$V_s = 0.458V_p - 0.3904 \qquad (8)$$

Where V_p is compressional wave velocity, V_s is shear wave velocity.

II. MATERIALS AND METHOD

Materials

The seismic refraction survey was done using a seismograph, geophone, P-wave seismic source, sledge hammer, measuring tape and global positioning system. A seismic system consists of two sets of cable with a twelve channel spread cable for vertical geophones connected to the acquisition box on each side.

Method

The twelve geophones were placed on a linear array and the seismograph box was set to connect the geophones spaced at 5m intervals. Seismic energy was produced by a source on the surface which travelled directly through the upper layer down to and then laterally along higher velocity layers before returning back to the surface. This energy was detected on the surface by the geophones. A sledge hammer and metal plates were used to generate seismic waves. P-wave was generated when the hammer was struck vertically on the metal plate. The generated energy penetrated into the subsurface and refracted off at different interfaces corresponding to geological boundaries and then returned to the surface at a later time to be picked up by the geophones and communicated to the seismograph which is displayed as seismogram (Figure 2).

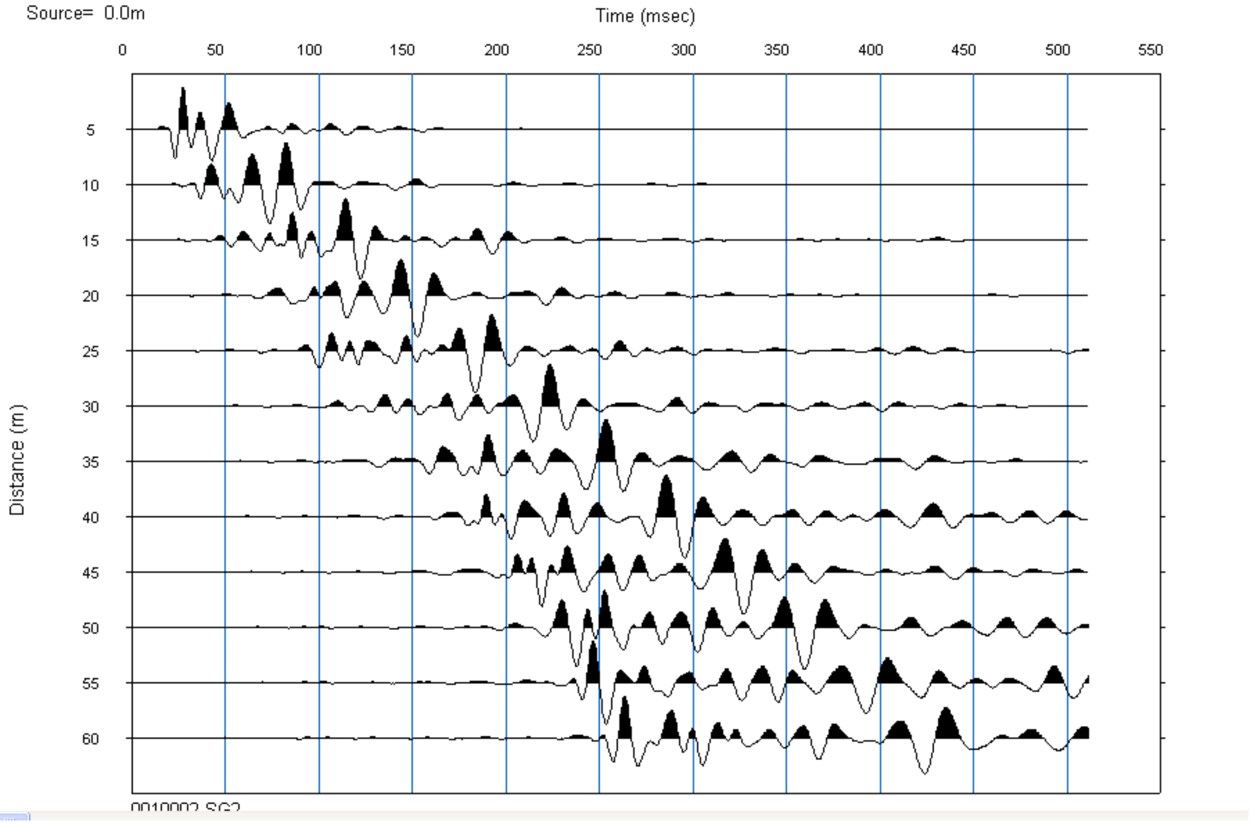


Figure 2: Arrival time of P-wave curve (One of the data information)

III. RESULTS AND DISCUSSION

Results

The aim of this research is to determine from the near surface, the local fit constants in the Eastern Niger Delta for shear wave velocity estimation from V_s-V_p relation. The first arrival time with corresponding separation from the seismic data was measured. The actual velocities of P-waves for proper interpretation have been determined. Shear wave velocity has been determined. Local fit constants for V_s-V_p relation have been obtained. We have compared the effect of local fit and Castagna constants on Poisson's ratio.

Near surface seismic data was used to investigate the local fit constants for V_s-V_p relation in order to estimate V_s from this equation. We were able to pick travel times with their corresponding separation using the paint package of Windows 7.1. The procedure resulted in Figures 3 to 9. Figure 10 presents the regression analysis of compressional wave velocity and shear wave velocity with necessary constants for local fit. Figure 11 compares the assumed compressional wave velocity with the Poisson's ratios obtained due to the effect of local fit constants and those of Castagna.

Table 1: Assumed values of V_p and V_s with effect of local fit constants and Castagna constants on V_p/V_s ratio.

S/N	V_p (m/s)	V_s (m/s) local	V_s (m/s) Castagna	V_p/V_s local	V_p/V_s Cas
1	300	183.5862	257.4576	1.63410975	1.1652404
2	350	214.1362	300.5626	1.63447376	1.1644829
3	400	244.6862	343.6676	1.63474687	1.1639154
4	450	275.2362	386.7726	1.63495935	1.1634744
5	500	305.7862	429.8776	1.63512938	1.1631218
6	550	336.3362	472.9826	1.63526852	1.1628335
7	600	366.8862	516.0876	1.63538449	1.1625933
8	650	397.4362	559.1926	1.63548263	1.1623902
9	700	427.9862	602.2976	1.63556675	1.1622162
10	750	458.5362	645.4026	1.63563967	1.1620654
11	800	489.0862	688.5076	1.63570348	1.1619334

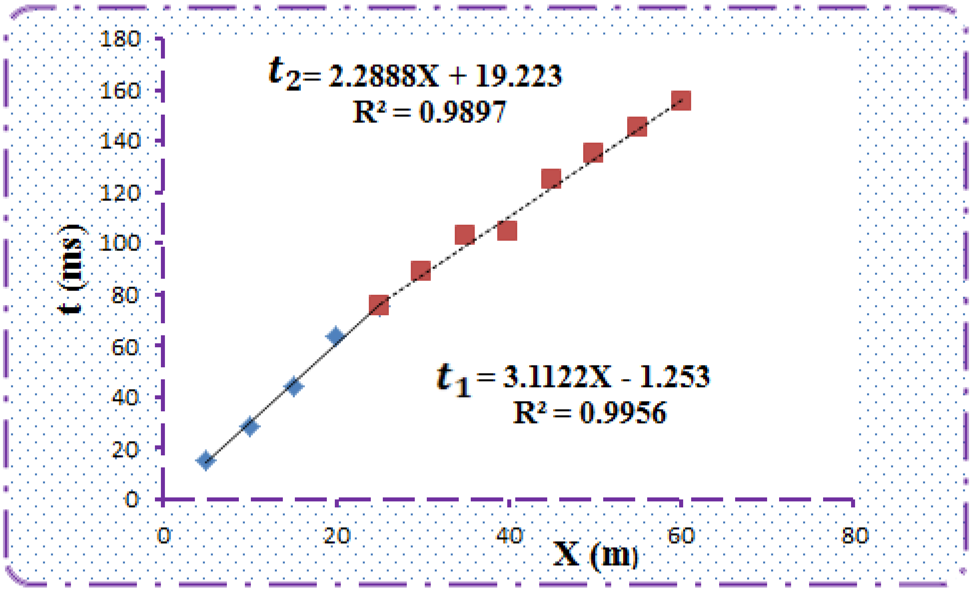


Figure 3: P-wave t-X curve from latitude 4.6384^{0}N and longitude 7.9174^{0}E.

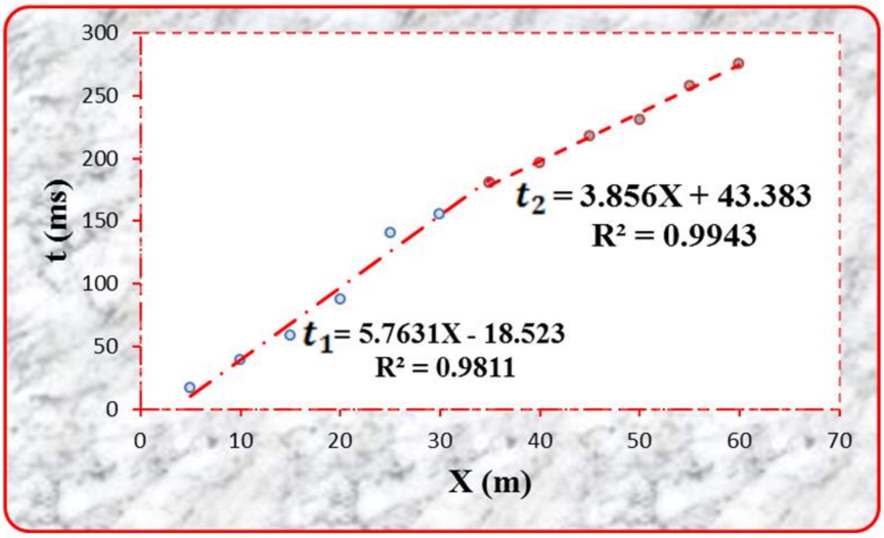


Figure 4: P-wave t-X curve from latitude 4.6500^{0}N and longitude 7.9333^{0}E.

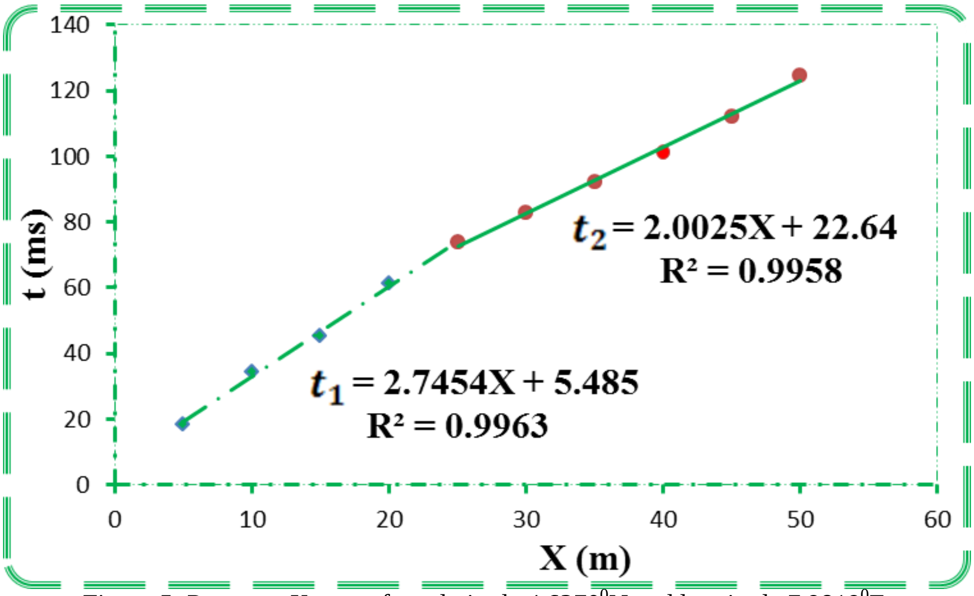


Figure 5: P-wave t-X curve from latitude 4.6370^{0}N and longitude 7.9819^{0}E.

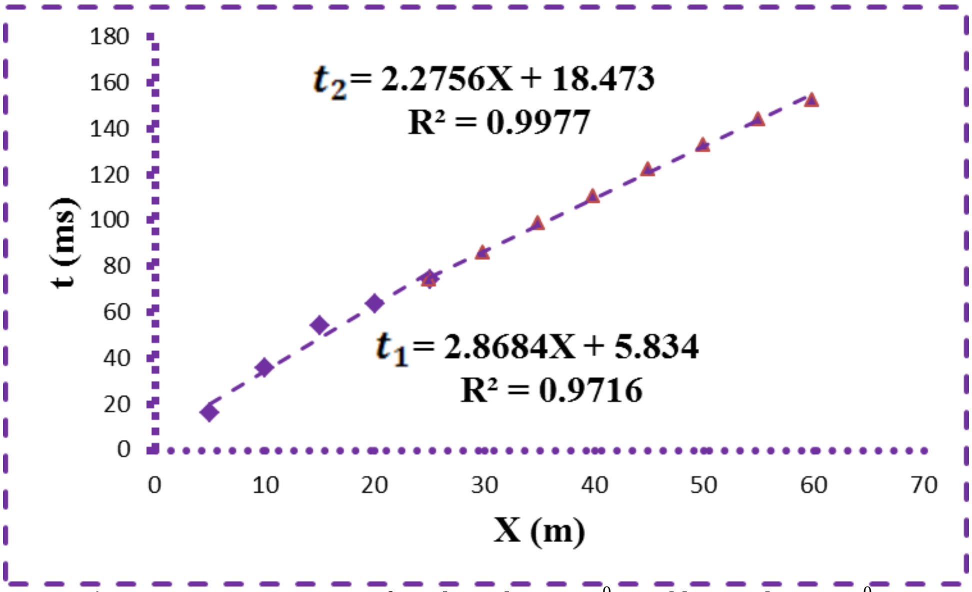


Figure 6: P-wave t-X curve from latitude 4.4746^{0}N and longitude 7.9238^{0}E.

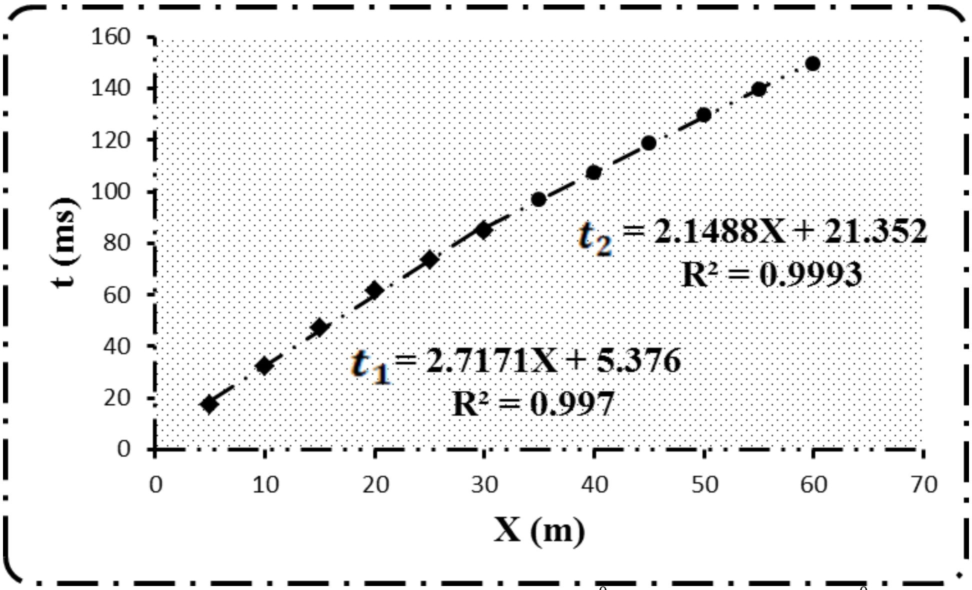


Figure 7: P-wave t-X curve from latitude 4.6732^{0}N and longitude 7.9814^{0}E.

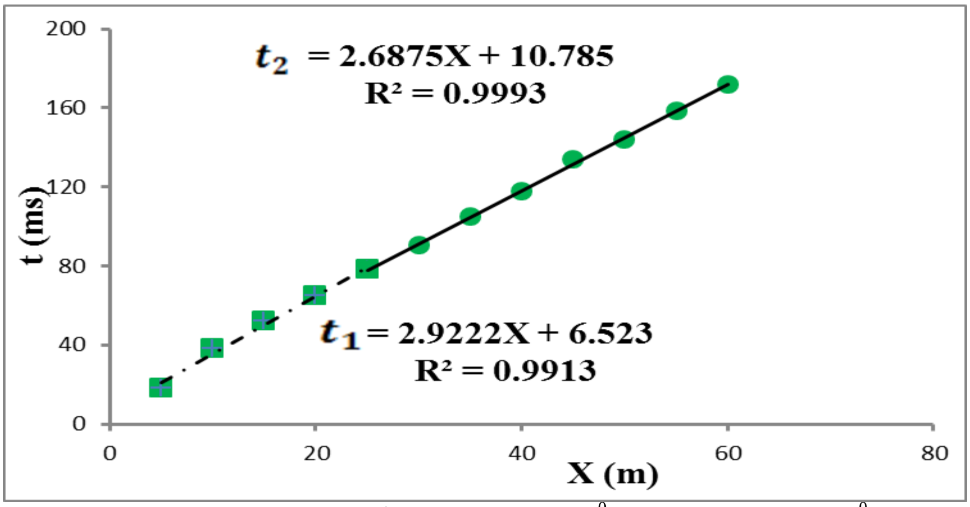


Figure 8: P-wave t-X curve from latitude 4.6574^{0}N and longitude 7.9779^{0}E.

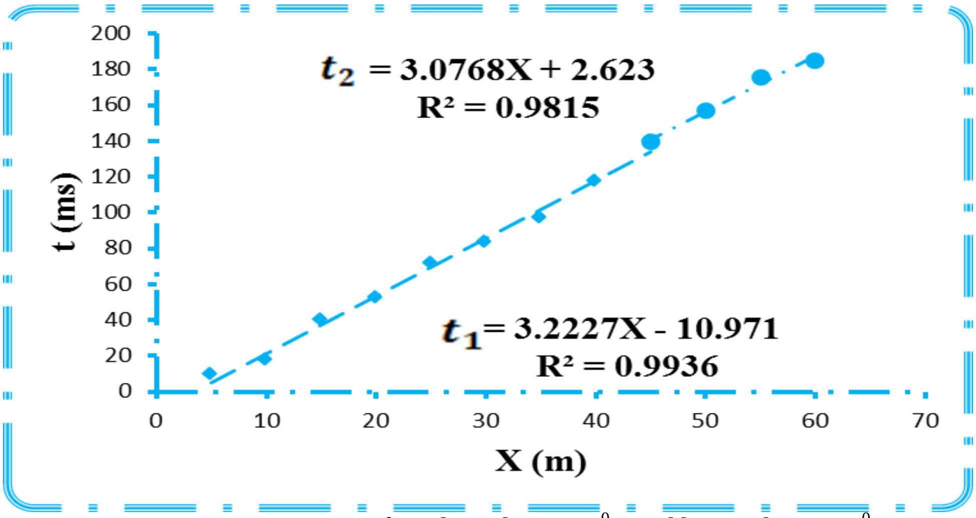


Figure 9: P-wave t-X curve from latitude 4.6765^{0}N and longitude 7.9228^{0}E.

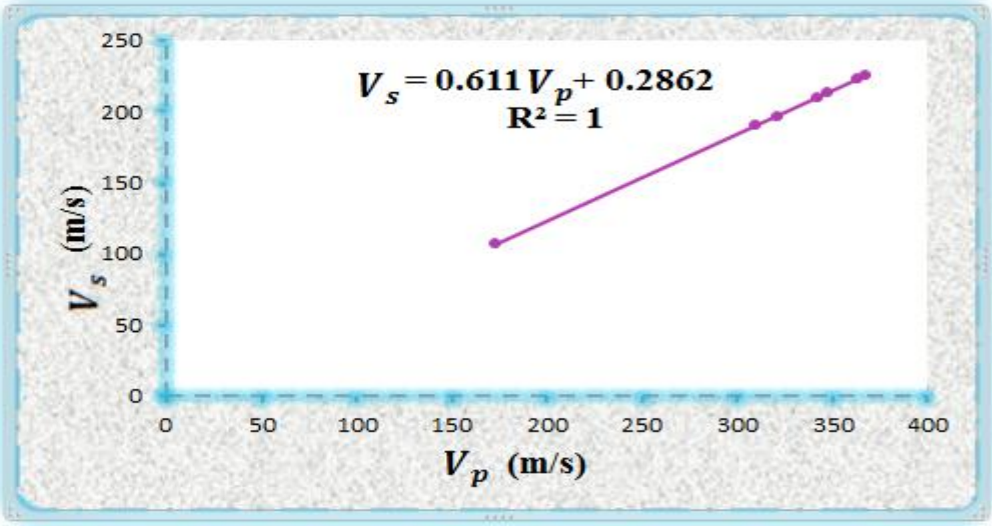
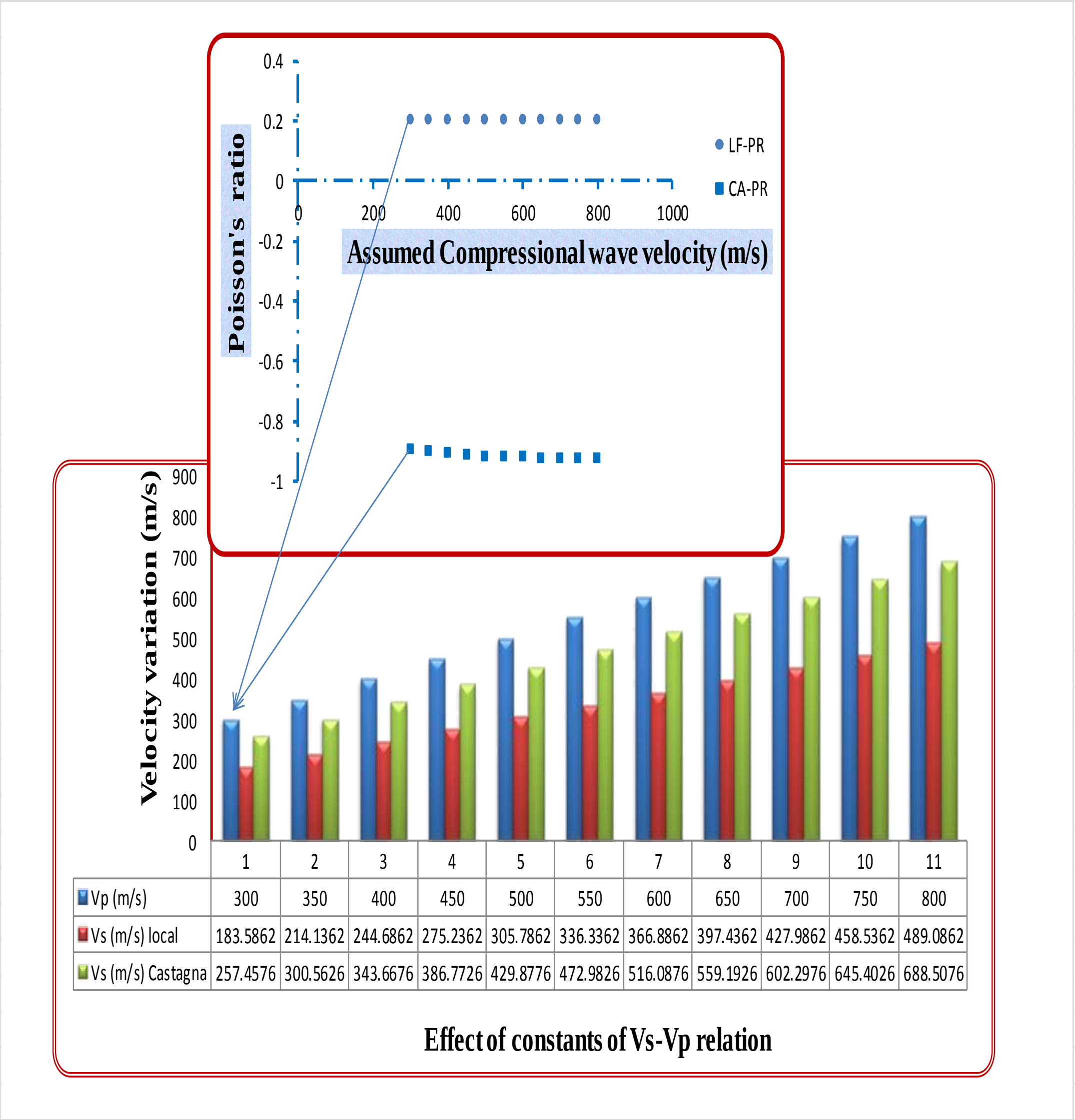


Figure 10: V_s-V_p relation with constants for local fits



	1	2	3	4	5	6	7	8	9	10	11
Vp (m/s)	300	350	400	450	500	550	600	650	700	750	800
Vs (m/s) local	183.5862	214.1362	244.6862	275.2362	305.7862	336.3362	366.8862	397.4362	427.9862	458.5362	489.0862
Vs (m/s) Castagna	257.4576	300.5626	343.6676	386.7726	429.8776	472.9826	516.0876	559.1926	602.2976	645.4026	688.5076

Figure 11: The effect of constants on Poisson’s ratio.

IV. DISCUSSION

This study enables accurate determination of shear wave velocity from Castagna Equation but with the effect of the near surface rock lithology in the area. With shear wave velocity and compressional wave velocity, information on Poisson's ratio, V_p/V_s ratio, elasticity, bearing capacity of the subsurface, immediate settlement of footings among others are possible.

Near surface seismic processes have been carried out in Eket. The results for different locations include latitude 4.6384^0N and longitude 7.9174^0E by Mobil peagasus club, Esuene Way (Figure 3), latitude 4.6500^0N and longitude 7.9333^0E at All Weather Road, Idua (Figure 4), latitude 4.6500^0N and longitude 7.9333^0E at Government Primary School, Main School Road (Figure 5), latitude 4.4746^0N and longitude 7.9238^0E at Government Primary School, Hospital Road (Figure 6), latitude 4.6732^0N and longitude 7.9814^0E by Salvation Army Primary School, Ikot Use (Figure 7), latitude 4.6574^0N and longitude 7.9779^0E by Heritage Polytechnic (Figure 8) and latitude 4.6765^0N and longitude 7.9228^0E by The Apostolic Church, Nduo Eduo (Figure 9).

Figure 3 is the result obtained from analysis of data from latitude 4.6384^0N and longitude 7.9174^0E. This gives rise to two layers with compressional wave velocities: V_{p1} and V_{p2} as 321m/s and 437m/s respectively. The data was displayed as seismogram. The first arrivals were picked using the paint package of Windows 7.1. This was used to generate a t-X curve. The reciprocal of the slopes of first and second layers enabled the compressional wave velocity information. Figure 3 also presents the regression relation for the first layer (Equation 9) and the second layer with strong coefficients of determination, highlighting very strong correlation coefficients. This approach was used to obtain Figures 4 to 9; the necessary information on the t-X relationships are stated in Equations 9 to 15.

$$t = 2.2888X + 19.223 \tag{9}$$

$$t = 5.7631X - 18.523 \tag{10}$$

$$t = 2.7454X + 5.485 \tag{11}$$

$$t = 2.8684X + 5.834 \tag{12}$$

$$t = 2.7171X + 5.376 \tag{13}$$

$$t = 2.9222X + 6.523 \tag{14}$$

$$t = 3.2227X - 10.971 \tag{15}$$

Equation 2 was used to determine the shear wave velocity information; Poisson's ratio was considered as 0.2 for sand. The linear plot of V_s against V_p resulted in Figure 10. This yields Equation 16. The constants for local fits were obtained as a = 0.611 and b = 0.2862. We assumed some V_p information as stated in Table 1 and subjected them to Castagna relation with Castagna constants and local fits constants. We observed that Castagna case generated very high Poisson's ratio of approximately 0.9 which is not common among sand. It shows over estimation of result. The local fit constants satisfied this lithology.

$$V_s = 0.611\, V_p + 0.2862 \tag{16}$$

According to Table 1, the average V_p/V_s ratio due to the effect of local fit constants is 1.64, but about 1.16 is due to Castagna effect. Local fit constants should be investigated before considering V_s-V_p relation for estimation of shear wave velocity. The effect of these constants (local fits and Castagna) with Poisson's ratio is highlighted in Figure 11. The P-value assessment is much lower than 0.01, showing highly significant outcome.

Most seismic data exist without shear wave velocity statistics. In order to obtain this missing parameter to enable other hidden information, a Vs-Vp relation became necessary. A sledge hammer and metal plate were used to generate seismic wave into the near surface. Compressional wave was generated when the hammer was struck vertically on the metal plate. The generated energy entered into the ground and refracted off at the various interfaces corresponding to geological boundaries and consequently, returned to the surface at later time to be picked by the geophones. The seismic waves received by geophones were converted into electrical pulse. The desired output was then recorded as seismogram which is the plot of the time of wave arrival against source-receiver separation.

The paint package of Windows 7.1 was used to pick the arrival time and separation from the seismic trace. These corresponding values were then used to plot t-X curves which indicate very strong correlation coefficients (almost 1.0). The inverse of slope (compressional wave velocity) was determined for both first and second layers. With the poison ratio of 0.2 for sand lithology, shear wave velocity was obtained and used to determine the local fit constants. Assumed compressional wave velocities were considered to compare the effect of these local fit constants and Castagna constants on the poison ratio which resulted in huge discrepancies. Therefore, it is necessary to investigate the local fit constants of any location not considered by Castagna during his survey.

V. CONCLUSION

Constants for V_s-V_p relation are basic information as they are responsible for accurate estimation of shear wave velocity from this relation. Castagna constants satisfied this relation but the accuracy of the result may not be appreciated as in the locations of this study. The local fit constants obtained in our research satisfied this relation. With the effect of the constants for local fits of V_s-V_p relation, assumed compressional wave velocity was also generated and used to determine shear wave velocity. A positive Poisson's ratio was obtained as it matches with the case of sand lithology in the near surface; negative values were obtained which is very far from accurate standard value for Poisson's ratio of sand lithology. Constants for local fit should always be determined before shear wave velocity is estimated from V_s-V_p relation. This result is adequate for near surface investigations in the Eastern part of Niger Delta, therefore, these local fit constants should be used due to huge discrepancies with those of Castagna.

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